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REMARKS ON OUR PRESENT KNOWLEDGE OF MASSES OF GALAXIES

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RESUMEN

Se discuten las masas estimadas de 230 galaxias; 180 de ellas con la línea de 21-cm y 50 con velocidades medidas ópticamente. Las masas promedio de las galaxias desde las S0 hasta las irregulares, disminuyen de $\cong 10^{11}$ a $10^{10}\,M_\odot$. Las espirales de barra parecen tener masas menores al compararlas con las espirales "normales" del mismo tipo, en la clasificación de Hubble. Se hace hincapié en este trabajo sobre el hecho de que las for-- maciones espirales no se desarrollan en galaxias con masas menores que $10^{10}\,M_\odot$.

ABSTRACT

Masses estimated to-date of 230 galaxies, 180 by the 21-cm line and 50 by optical velocities are discussed. The average mass of galaxies from S0 on to irregulars, decreases from $\cong 10^{11}$ to $10^{10}\,M_\odot$, as shown earlier. Barred spirals seem to have smaller mass compared with "normal" spirals of the corresponding Hubble type. It is emphasized that spiral formations are not developed for masses below $10^{10}\,M_\odot$.

Key words: **GALAXY MASSES — SPIRALS.**

I. INTRODUCTION

In the past two decades researches leading to the estimate of masses of galaxies have been numerous. All estimates are based on the observed kinematical properties of galaxies. For flat systems, the spirals, it is assumed that the dominant motion is one of rotation, and the dispersion of velocities negligible relative to rotation; while for ellipticals, rotation is considered negligible with respect to the dispersion of velocities. In all cases a model for the mass distribution is adopted.

A review of the masses of galaxies determined by optical data is given by Burbidge and Burbidge (1975) while masses obtained from the 21-cm HI data are reviewed by Roberts (1969, 1975).

In these papers Roberts discussed, as a function of galaxy type, the ratios: M/L, M of hydrogen to total mass, M_H/L, etc., but total masses alone as a function of type are not discussed explicitly. We believe that the total mass a galaxy possesses at present is its primeval mass. Hence total mass is a property which may be of prime significance in the morphological history of a galaxy. For this reason and considering that more mass estimates are now available both by radio and by optical means we deemed it of interest to look into the overall properties of known galaxian masses.

To-date there exist estimates of mass for about 230 galaxies; 180 are based on the 21-cm HI line. Many of these are "indicative" masses obtained from the total profiles of the 21-cm line and by essentially the use of the Brandt model or the Bottlinger-Lohmann model.

Galaxies with mass estimates from optical velocities are about 50 in number. As a rule the models adopted for spirals consist of concentric spheroids either homogeneous in density or inhomogeneous. Very seldom are thin disk models invoked. The relative merits of these models are discussed by Burbidge and Burbidge (1975).

II. MASSES OF GALAXIES RELATED TO MORPHOLOGICAL TYPE

The following figures summarize the results obtained from the existing mass estimates.

Figure 1 shows the dependence of optically obtained masses on Hubble type. Open circles denote the average mass, in solar units, of galaxies within the interval of morphological type indicated on the abscissa where the number of galaxies in the sample is also given. The barred spirals (filled circles) are plotted separately; again the number contained in each sample is given. In all cases bars indicate the standard deviations.

Elliptical galaxies are included in Figures 1 and 2 for the sake of completeness. Reliable mass estimates for these objects are scanty and the sample appears to suffer observational selection as it is biased towards more massive ellipticals. It is also

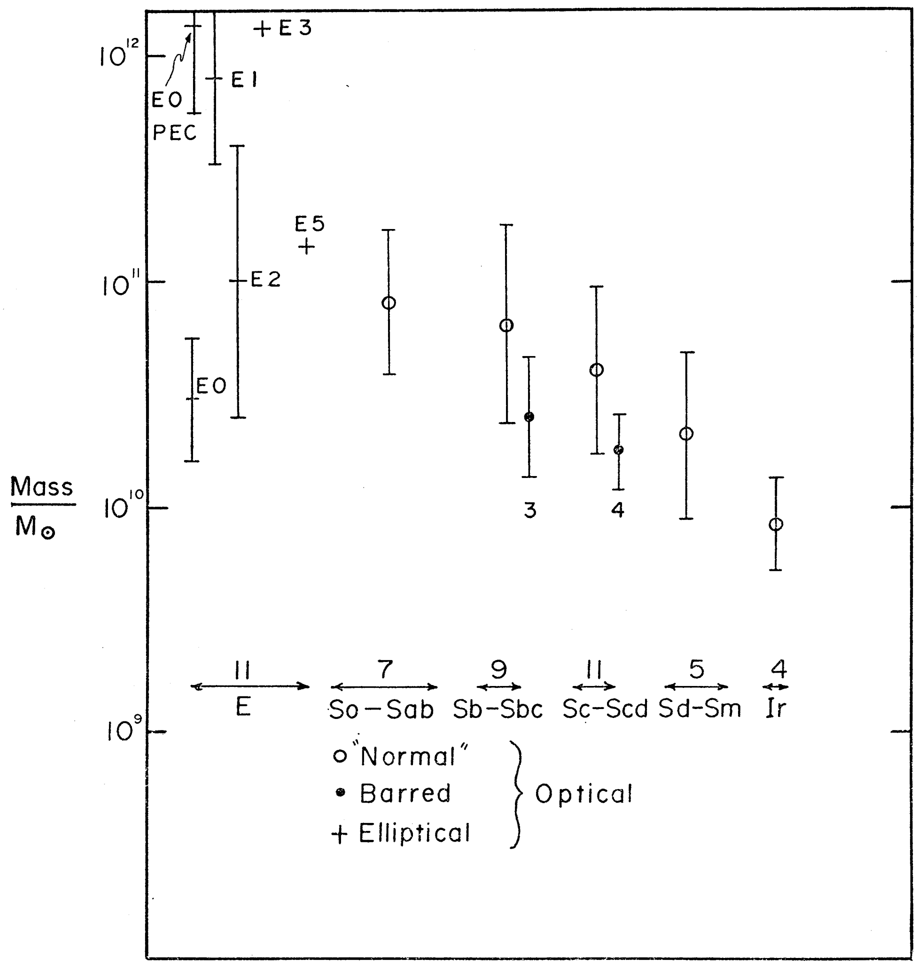

FIG. 1. Mean mass of galaxies, within the indicated interval of Hubble type, obtained from optical data. The number of galaxies in each sample is also given. Barred galaxies are plotted separately and the number of galaxies in each sample is again indicated, under the respective points. Vertical bars stand for the standard deviations.

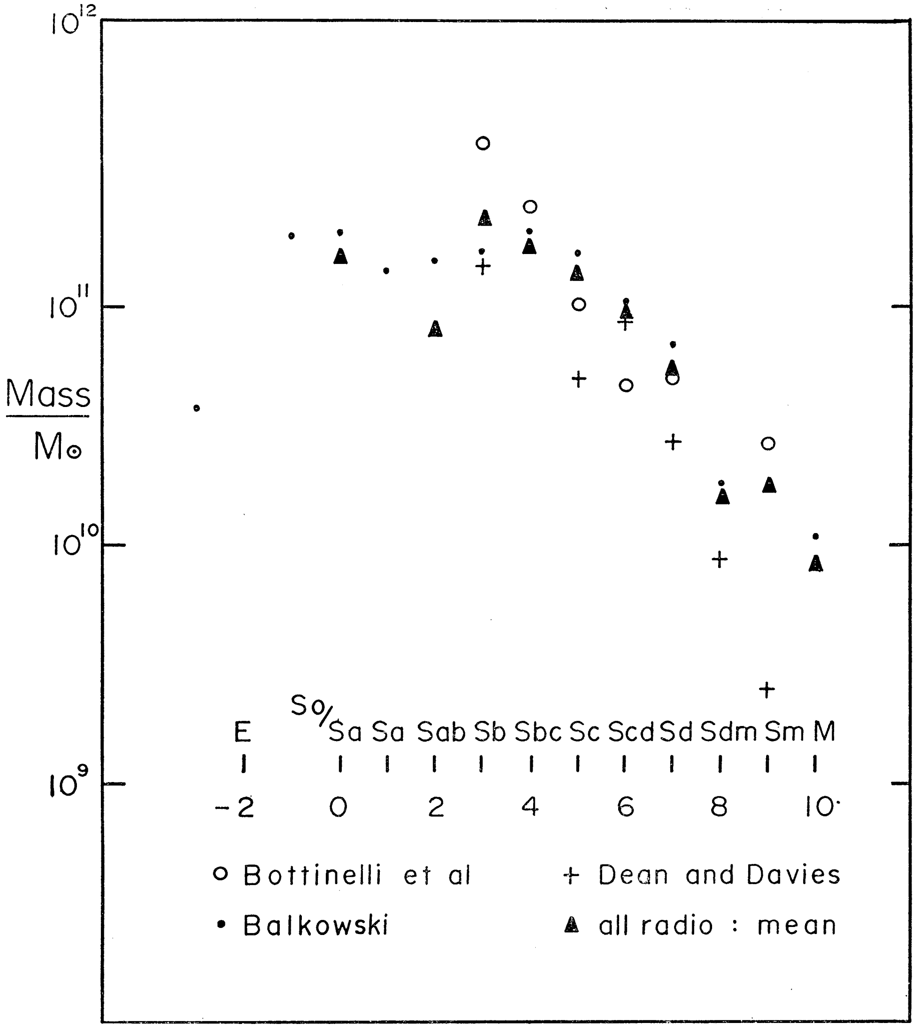

FIG. 2. Mean mass, mostly "indicative" within each galaxy type, from HI data, obtained by different authors.

worth noting that recent estimates of the dispersion of velocities on which the mass estimates of ellipticals are based tend to yield values lower than earlier determinations by a factor of about 0.5. Under these circumstances we feel that ellipticals do not warrant a meaningful statistical treatment at this stage. Therefore we shall not discuss them further except to say that their masses show a large scatter. Taking the known masses at face value the mean of the 11 ellipticals is 8×10^{11} $M_\odot$.

For spirals the following conclusions can be drawn:

1) The masses of galaxies decrease from S0 to irregulars.

2) Barred spirals are less massive than "normal" spirals.

We now compare mass estimates, from different authors, all from HI data. In Figure 2 we have plotted for each interval of morphological type the average of mostly "indicative" masses from 21-cm data. Open circles stand for masses by Bottinelli *et al.* (1968) 28 in all. Balkowski's extensive work (1973) has yielded masses for 116 galaxies, averages

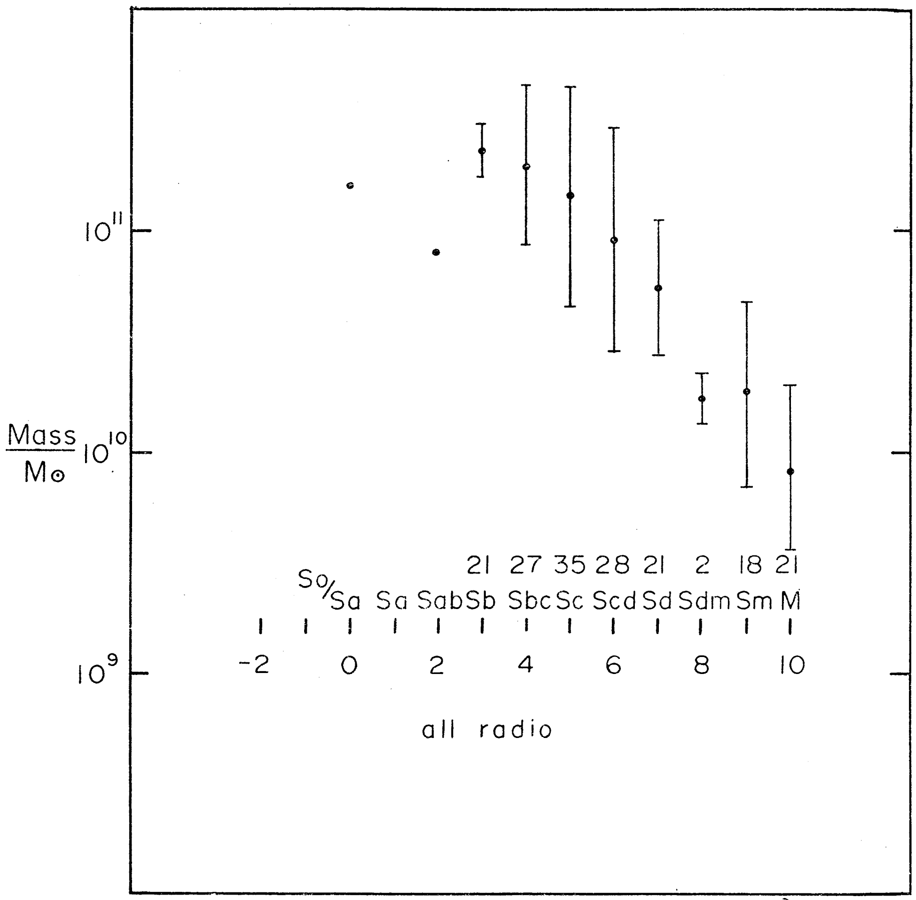

FIG. 3. Mean mass from all 21-cm data as a function of galaxy type.

of which are shown by small filled circles. A recent investigation by Dean and Davies (1975) gives indicative masses for 17 galaxies; averages based on the latter data are shown by crosses. These masses, the authors state, are based on an improved procedure. Finally triangles stand for the averages of all radio determinations combined, namely, the above three and all other existing mass estimates.

Again a decrease of mass from S0 to irregulars is apparent. For Sb and Sc types masses from Bottinelli *et al.* are larger than the other determinations. We also note that masses from Dean and Davies are definitely the smallest.

Averages of all 21-cm mass estimates as a function of galaxy type are given in Figure 3, with standard deviations (bars). The number in each sample is also indicated; in all our graphs the ordinates are the masses in solar units on a logarithmic scale. And finally Figure 4 gives the average mass versus interval of galaxy type of all known optical and radio masses.

III. DISCUSSION

From the foregoing figures it is clear that, excepting the irregulars, the masses of spirals obtained from HI observations are larger than the optical ones by about a factor of 2. This conclusion was reached earlier by other authors (e.g., Roberts 1969). The main reason for this is probably the fact that for mass estimated from the 21-cm line one uses the Brandt or the Bottlinger-Lohmann model. As is well

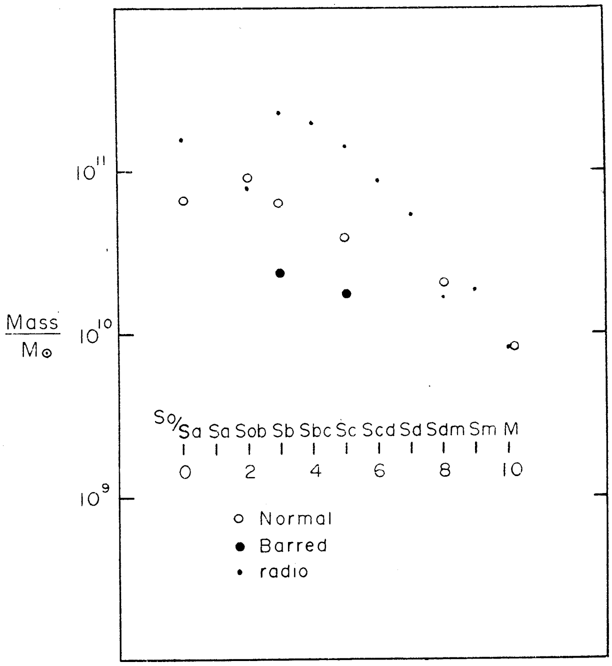

FIG. 4. Plot of average mass versus interval of galaxy type using all known optical and radio masses; E galaxies are left out.

known these models take care of the contribution of the outer unobserved regions. But in so doing the assumption is implicit that the rotation curve beyond the last observed point is represented by the assumed rotation law. Optical determinations of mass, on the other hand give the mass to the last observed point beyond which the galaxy may have more mass bound to itself. Incidentally, in both cases the assumption of pure circular rotation all along the galaxy and thus the neglect of the dispersion of velocities in the nuclear bulge, where the random motions are considerable, may lead to underestimated masses.

It is interesting to note that in nearby galaxies, like M 31, optical and radio masses are quite comparable. The same can be said about irregulars. The optically accessible ones are the nearby irregulars, of which one can probably observe the entire extension.

The larger masses from HI data may mean that neutral hydrogen extends or can be observed farther than the optically observed regions (H II regions) of a galaxy, the more so as one goes to earlier galaxy types; this is supported by the results of Lewis and Davies (1973) among others, in that the HI content in a spiral is higher in early types and diminishes for later types.

To illustrate that the Brandt model yields larger masses we have the case of NGC 5055 at a distance of 7.4 Mpc (H = 75). There exist two determinations of mass based on the very same rotation curve: using the inhomogeneous spheroid model Burbidge, Burbidge and Prendergast (1960) estimate a mass of 5.5×10^{10} M⊙ while Brandt and Belton (1962) based on the same rotation curve and using the flat disk model estimate a mass of 1.1×10^{11} M⊙, larger than the first by a factor of 2. It would be instructive to have more of such determinations done using identical observational data but different models.

IV. CONCLUSIONS

Masses available to-date confirm the tendency that these decrease from earlier through later type spirals to irregulars. The masses based on HI data are larger than optical masses by about a factor of 2. What does not seem to be emphasized so far, to our knowledge, is that barred spirals tend to have smaller masses than "normal" spirals of the corresponding type. Although determination of mass in barred spirals may be less reliable due to the assumption of rotational symmetry which may not be a good one for these objects, it is still significant that the masses of SBb and SBc spirals (with 3 and 4 in the sample respectively) fall systematically below that of normal spirals (see Figure 4).

It also appears that irregulars with plenty of H II regions and no well organized spiral pattern do not have masses larger than 10^{10} M⊙. Would this mean that the range of total masses for a spiral structure to develop is limited? We suggest in concluding that very small mass galaxies do not develop spiral structure; and that there exists a range of masses within which a galaxy may develop spiral structure. This may be a sufficient condition but not a necessary one. The question whether an upper limit of the mass exists or not may be answered when more reliable values for the masses, especially of the elliptical galaxies, are obtained.

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